Research into Effects of Atmospheric Volcanic Degassing

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Table of Contents

Abstract

The purpose of this thesis is to examine the effects of volcanism on the atmosphere. One effect of volcanism is cooling of the atmosphere after a major eruption. The approach in this project is to use the results of published work to document the impact of volcanism on the atmosphere. This entails considering the formation of volcanoes, and the mechanisms of volcanic eruptions. The results of the research show that after some major eruptions, the planet goes into a period of cooling. The cooling effects is due to the enormous amounts of sulfur dioxide released into the atmosphere. When sulfur enters the atmosphere and interacts with water vapor, sunlight, and oxygen, it creates sulfuric acid aerosols. These aerosols in the atmosphere create a veil that reflects sunlight back into space causing the earth to go into a period of cooling. Also, the magnitude of the cooling effect is affected by the latitude which the eruption occurred. The effects of lower latitude eruptions spread more rapidly than the effects of eruptions at higher latitudes.

Acknowledgements

Thank You Everyone,

I would like to dedicate my thesis and senior year to everyone who has gotten me to this point. I would like to thank my parents for letting me live with them while attending college. The United States Department of Veterans Affairs and Veterans Office of Ohio State University have supported me financially while attending Ohio State University. Thank you to my professors and fellow students in teaching me and getting me through my college career as a student of the School of Earth Sciences. A special thank you to Dr. Barton on being my advisor for my thesis paper. I look forward to graduating at the end of the Autumn 2015 semester and continuing my work and education in future endeavors.

Introduction

Throughout, volcanic activity has shaped our planet from the smallest to the largest eruptions. Some eruptions have changed the history of human civilization through the centuries, from the destruction of Pompeii to the creation of the Hawaiian Islands. As humanity continues to confront the destructive and life giving force of volcanic activity we have gained further understanding of volcanic eruptions and how they continue to influence the planet. We have gained much understanding of how volcanic activity is related to tectonic forces. While all volcanoes share some common characteristics, there are differences in the volume and composition of the gas species dissolved in the magma residing in reservoirs, or chambers, beneath volcanoes. Release of these pressurized gases is the dominant controlling factor in the strength of an eruption and, ultimately, to the impact of eruptions across the planet. Further studies on volcanic degassing will provide a better understanding of volcanic eruptions, and the impact they can have on the across the planet.

Methods

The method utilized in this project involves compiling the results of research by other workers to assess the effects of impact of volcanism on the atmosphere. This requires utilizing databases and internet sources to find pertinent information about volcanic processes and the effects of volcanism.

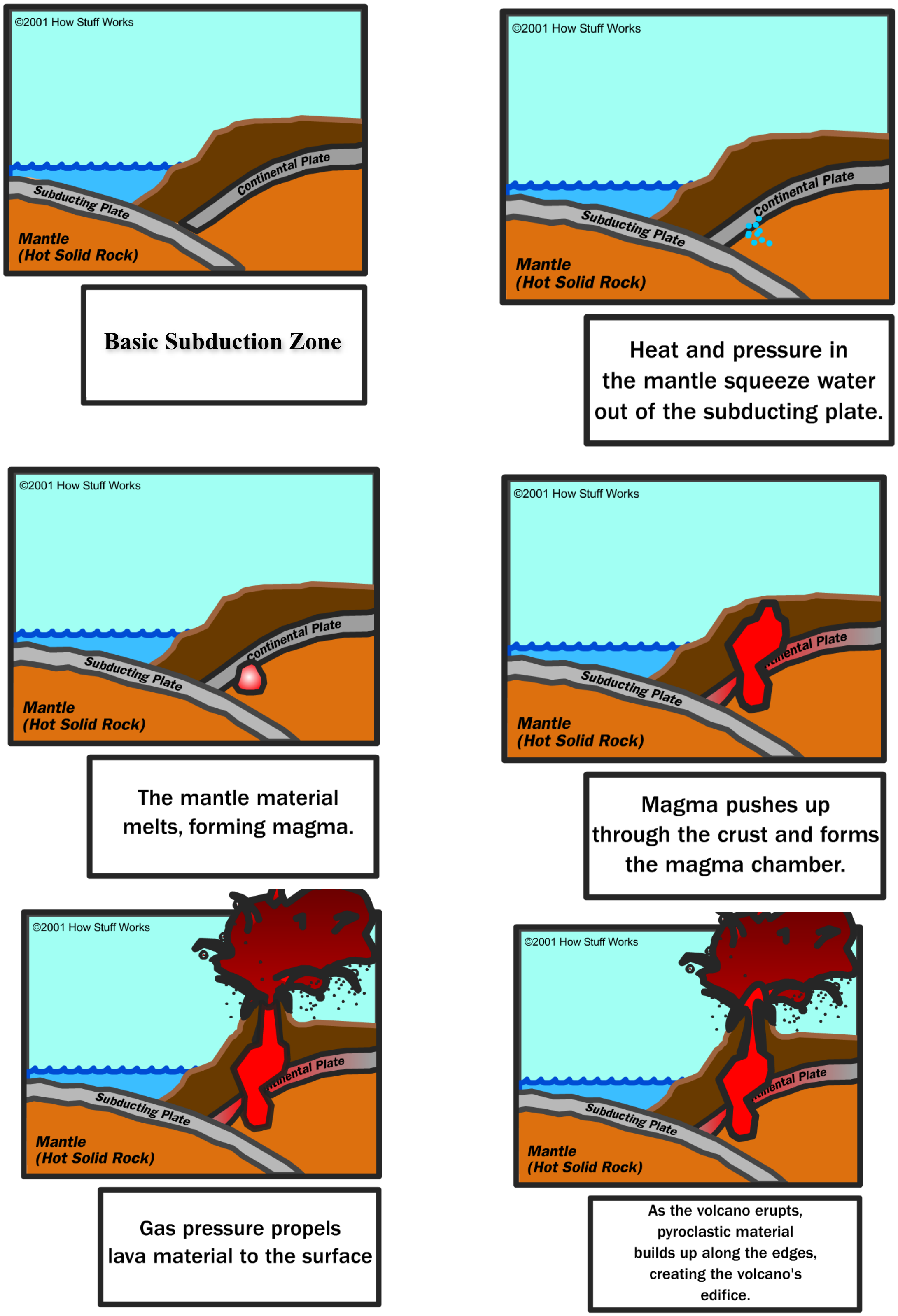
Results

The formation of many volcanoes occurs above subduction zones where two tectonic plates collide, and the denser plate subducts beneath the less dense plate. Normally, as the plate sinks into the mantle, it will remain solid as the mantle because the temperature is too low for the plate to melt. The increase in pressure and temperature as the plate subducts causes water and other volatiles trapped within the subducting plate to be released into the overlying mantle wedge. The release of water, in particular, from the subducting plate triggers melting as it rises upwards through the mantle wedge. Once the mantle begins to melt, the molten material rises to the surface creating a volcano above the subduction zone. Figure 1 provides a visual summary of the magma forming process and volcanic at convergent margins (Harris, 2001). The Pacific Ring of Fire is an example of a series of subduction zones above which many volcanos have formed around the Pacific Plate.

Other volcanoes form along the boundary of two tectonic plate boundaries that separate from each other, which is known as divergent boundary. The Mid-Atlantic Ridge is an example of a divergent boundary. The volcanism found at these location are associated with hydrothermal vents. Melting to produce magma at divergent boundaries results from decompression melting of mantle that rises to fill the space between the separating plates.

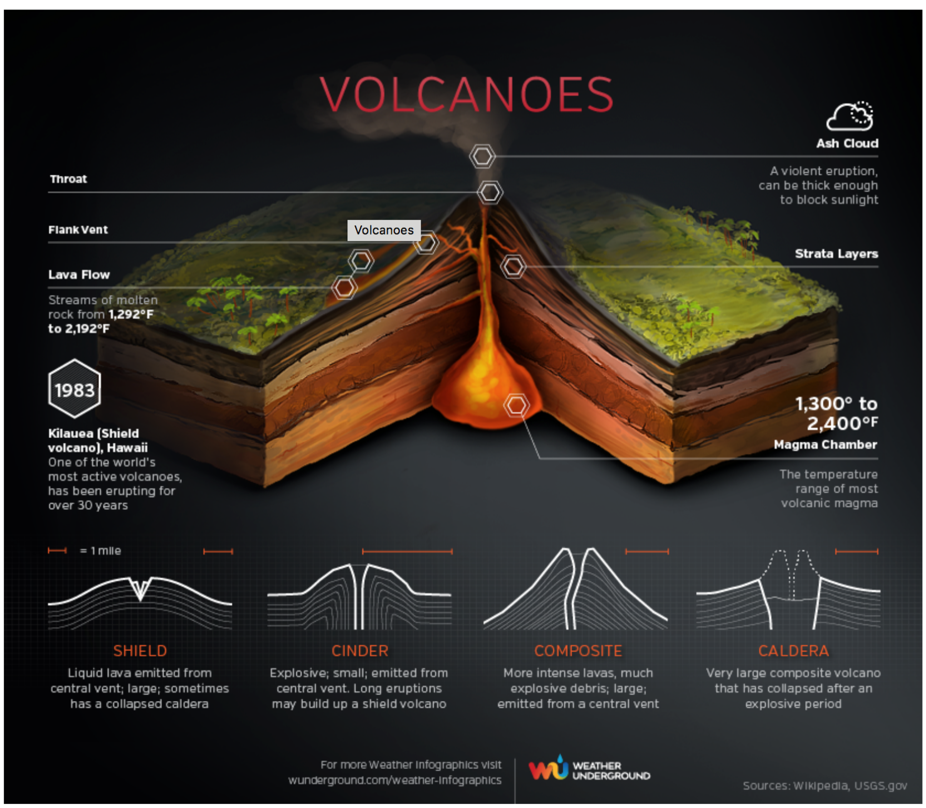
A third location for formation of volcanoes is at hot spots that form above mantle plumes, hot mantle that rises beneath a tectonic plate and undergoes decompression melting to produce magma that ascents and erupts to form volcanoes such as those on the Hawaiian Islands and at Yellowstone National Park (Harris, 2001).

Figure 1
Depiction a Volcano Forming



The structure of most volcanoes consists of a summit crater and a central vent that feeds magma to the surface from a reservoir or chamber located deeper in the crust. The summit crater is the "mouth" of a volcano through which lava or pyroclastic material is vented and can interact with the earth's atmosphere. The magma chamber is the chamber where magma is stored beneath the surface between eruptions. The central vent (throat) is the connection between the summit crater and the magma chamber which allows magma to ascend and for volcanic eruptions to occur. The three main types of volcanoes include stratovolcanoes, cinder cone volcanoes, and shield volcanoes. The type volcano is dependent upon the viscosity of the magma, and the amount of gas contained in the magma (Volcano Hazards, 2015). Figure 2 shows the structure a volcano with labels (Weather Underground, 2015). If the magma has a low viscosity the gases in the magma will more easily escape. If this is the case and there is a small amount of gas within the magma, the eruption results in lava flows creating a shield volcano similar to the Hawaiian Islands. On the other hand, if

Figure 2 Diagram of a Volcano Structures



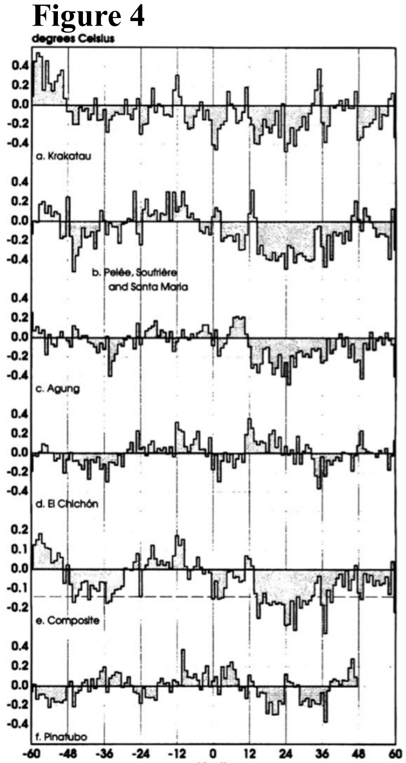
the viscosity of the magma is high and the amount of gas within the magma is large, the eruption is explosive, resulting in a cinder cone volcano (like Capulan Mountain) or a stratovolcano (like Mount Saint Helens) (Volcano Hazards, 2015). Refer to Figure 1 for the processes involved in volcano formation (Harris, 2001).

When a stratovolcano erupts it releases large amounts of gas and material into the lower stratosphere. Some eruptions have caused major climate disruption and have affected the atmosphere dramatically. Notable eruptions that have affected the climate include Mount Pinatubo (1991), Krakatau (1883), and Mount Tambora (1815). These three eruption produced short term climatic effects in the atmosphere but are well documented and well-studied. Each of these eruptions released large quantities of sulfur dioxide gas into the atmosphere, resulting in atmospheric disturbances across the planet (Langmann, 2014). Figure 3 shows an image of the Mount Pinatubo 1991 eruption (Newhall et al. 2005). Volcanological and petrological studies indicate that it is the quantity of sulfur dioxide released into the atmosphere due to volcanic degassing, rather than the magnitude of the explosion that causes the

Figure 3 Image of Mount Pinatubo 1991 Eruption

wide spread effect of cooling across the planet (Lyons et all, 1990). However, the eruptions must be sufficiently powerful to inject sulfur dioxide into the stratosphere. To evaluate this hypothesis, two volcano eruptions were analyzed: Mount Saint Helens (1980) and El Chichón (1982). These eruptions were of similar strength, but El Chichón released 8 Mt of sulfur dioxide aerosols, compared the 1 Mt sulfur aerosols released by Mount St. Helens. After the eruption of El Chichon, the earth experienced a cooling event whereas no significant cooling occurred after the Mount Saint Helens eruption (Volcano Hazards, 2015). Following studies of these two volcanic eruptions, it is widely accepted by the volcanic research community that the climate change after an eruption is caused by the sulfur aerosols injected into the stratosphere and not by the volcanic ash cloud (Langmann, 2014).

Figure 4

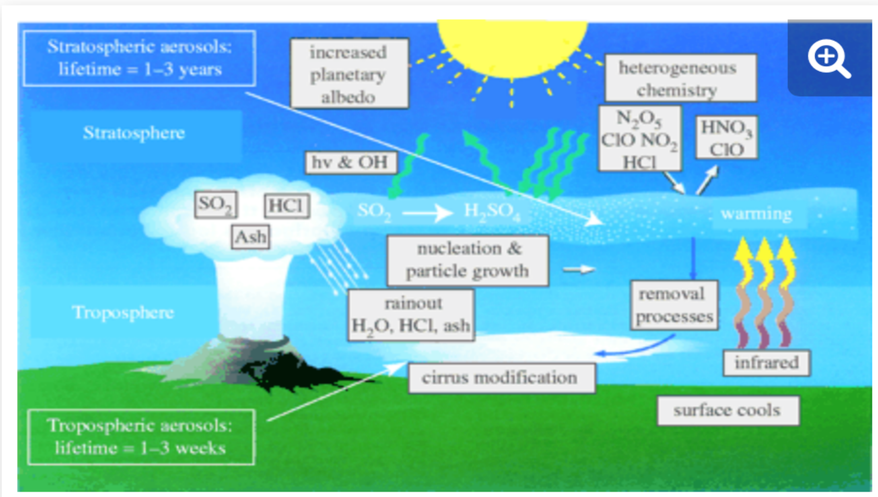


Monthly global-mean surface air temperature profiles for: (a) the Krakatau eruption (1883); (b) Pelée, Soufrière and Santa Maria (1902); (c) Agung (1963); (d) El Chichón (1982); (e) composite based on events (a–d); and (f) Pinatubo (1991). The data are expressed as departures in degrees Celsius from the appropriate monthly mean for the 5 years preceding month zero, the January of the eruption year. The dashed horiontal line indicates the 5 percent significance level

The Mount Pinatubo eruption emitted the largest sulfur dioxide cloud recorded since satellite observations began in 1978. This eruption caused the average surface temperature of earth to drop by 1.3 ºC (Volcano Hazards, 2015). The data plotted in Figure 4 show the average temperatures of the earth before and after several eruptions. The data show that that the average temperature dropped approximately 0.4ºC after major eruptions (Kelly et al. 1996).

The cooling effect of eruptions is due to sulfur dioxide (SO_2), oxygen (O_2), and water (H_2O) mixing together to form sulfuric acid (H_2SO_4) through photolytic reactions in the atmosphere. The resulting sulfur-rich aerosols induce cooling by scattering shortwave solar radiation back into space, which reduces the total amount of solar radiation reaching the earth's surface (Langmann, 2014). Figure 5 illustrates the effect of volcanic gas emissions on the atmosphere and on surface temperatures (Self, 2006).

Figure 5



Schematic diagram of various volcanic inputs to atmosphere and their interaction, fates, and radiative impact, including the formation of sulphuric acid (sulphate) aerosols (after **McCormick *et al.* 1995**; **Robock 2000**). See text for description of processes illustrated.

The location of a major eruption also is a factor on the magnitude of atmospheric and climatic effects. The products of eruptions at lower latitudes (between 30º N and 30º S) are more likely to spread across the planet compared with the products of eruptions at higher latitudes (above 30º N / 30º S). Atmospheric circulation at low latitudes involves movement of air masses towards the poles, and is thus able to spread erupted material across the planet into the higher latitudes. The products of eruptions at higher latitudes normally stay in the hemisphere in which the eruption occurred and do not spread so much over the surface (Viner and Jones, 2000). Since Mount Pinatubo is located at 15º N, the latitude of the eruption further enabled the spread of the ash and aerosol cloud over a wide area. Within three months of the eruption, Mount Pinatubo's ash cloud had reached both poles of the earth (Self, 2006).

In conclusion, understanding volcanoes starts with the understanding the relationship between volcanoes and tectonic setting. Volcanoes on different tectonic settings share broad similarities in structure and plumbing systems. However, there are differences in the nature of the material erupted and in the concentrations of dissolved gases in the magmas involved in the eruptions. Currently, it is accepted that the pressurized gases released during an eruption are the primary cause of climate disturbance after a major eruption. Further studies of volcanic degassing will continue to influence our view of the planet. As we continue to learn more about our planet, humanity will continue to be drawn to the beautiful but destructive power of volcanos.

Discussion

The results of this study show that the leading cause of atmospheric disturbance is the amount of sulfur dioxide release in a volcanic eruption. As the sulfur dioxide mixes with oxygen and water it creates sulfuric acid through photolytic reactions with sunlight in the atmosphere. The presence of these aerosols in the atmosphere induce cooling by scattering shortwave radiation back into space. As less short wave radiation reaches the earth's surface, the latter experiences a period of cooling. The location of the volcano has to be taken into account to assess the impact of major volcanic eruptions on the climate system. Eruptions at lower latitudes allow sulfur-rich aerosols to spread widely across the planet. On the other hand, the products of eruptions at higher latitude eruptions will stay in the same hemisphere.

Suggestions for Future Research

By studying the effects of volcanic degassing on the atmosphere, humanity will better understand earth's processes. After looking into the effects of volcanic atmosphere degassing, what are other effect of volcanism? Researchers can consider the effects volcanoes can have on the oceanic environment. The Hawaiians Islands are a chain of volcanic islands created by a hot spot in the Pacific Plate. The hot spot is still actively producing underwater volcanoes and islands. With volcanic activity still occurring researchers can look into the effects of new volcanoes growing in an underwater environment. Further research can be focus on studying mid-ocean ridges such as the Mid-Atlantic Ridge. Further studies on mid-ocean ridges can lead to understanding the dynamics of the early earth and the current effects of seafloor spreading. By studying the effects of underwater volcanic eruptions, humanity can further understand the world that we live on.

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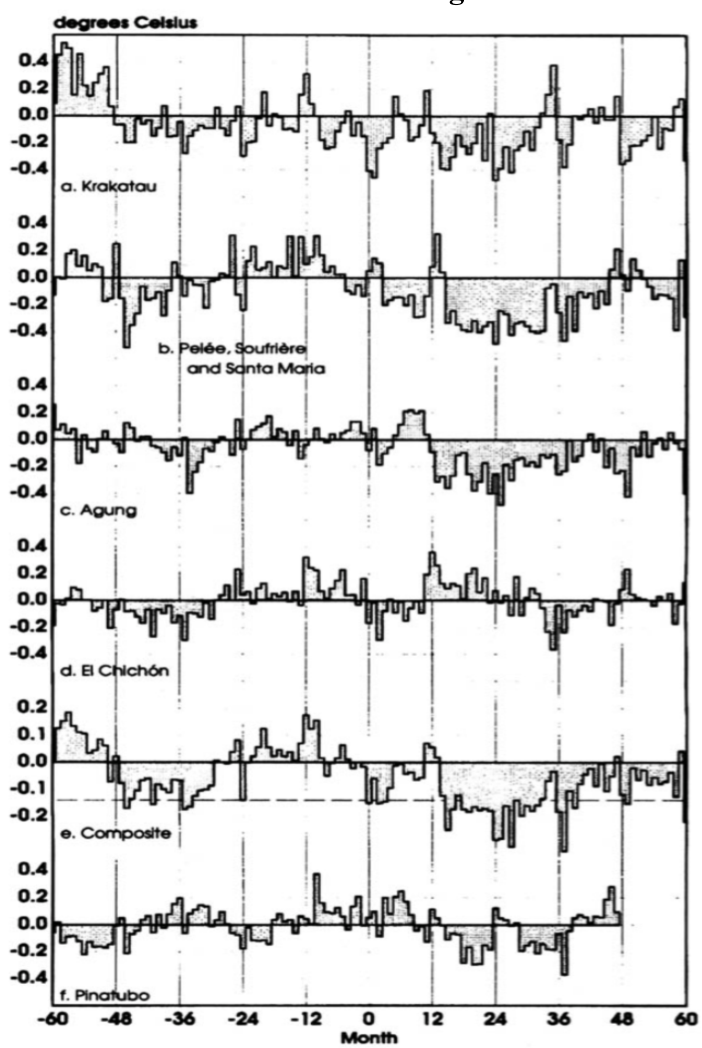
Appendix

Figure 4 shows analyzed studies of disturbance of cooling after a major eruptions. Kelly et all (1996) studied the atmosphere before and after an eruption showing the cooling disturbance of the atmosphere after an eruption. The data show the effects of cooling after the first January of a major eruption. The researched showed that the average temperature of the earth dropped about 0.4ºC (Kelly et al. 1996).

Figure 4



. Monthly global-mean surface air temperature profiles for: (a) the Krakatau eruption (1883); (b) Pelée, Soufrière and Santa Maria (1902); (c) Agung (1963); (d) El Chichón (1982); (e) composite based on events (a–d); and (f) Pinatubo (1991). The data are expressed as departures in degrees Celsius from the appropriate monthly mean for the 5 years preceding month zero, the January of the eruption year. The dashed horiontal line indicates the 5 percent significance level